Sun-Pointing-Error Correction for Sea Deployment of the MICROTOPS II Handheld Sun Photometer

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ABSTRACT

Handheld sun photometers, such as the MICROTOPS II (manufactured by Solar Light, Inc.), provide a simple and inexpensive way to measure in situ aerosol optical thickness (AOT), ozone content, and water vapor. Handheld sun photometers require that the user manually point the instrument at the sun. Unstable platforms, such as a ship at sea, can make this difficult. A poorly pointed instrument mistakenly records less than the full direct solar radiance, so the computed AOT is much higher than reality. The NASA Sensor Intercomparison and Merger for Biological and Interdisciplinary Oceanic Studies (SIMBIOS) Project has been collecting maritime AOT data since 1997. As the dataset grew, a bias of the MICROTOPS II data with respect to other instrument data was noticed. This bias was attributed to the MICROTOPS II measurement protocol, which is intended for land-based measurements and does not remove pointing errors when used at sea. Based upon suggestions in previous literature, two steps were taken to reduce pointing errors. First, the measurement protocol was changed to keep the maximum (rather than average) voltage of a sequence of measurements. Once on shore, a second screening algorithm was utilized to iteratively reject outliers that represent sun-pointing errors. Several versions of this method were tested on a recent California Cooperative Oceanic Fisheries Investigations (CalCOFI) cruise, and were compared to concurrent measurements using the manufacturer-supplied protocol. Finally, a separate postprocessing algorithm was created for data previously gathered with the manufacturer-supplied protocol, based on statistics calculated by the instrument at the time of capture.

1. Introduction

This note is an extension and validation of the recommendations made in Porter et al. (2001) with regard to problems associated with proper sun pointing using a MICROTOPS II (Solar Light, Inc.) sun photometer. Porter et al. (2001) showed that rough sea conditions can cause a bias in aerosol optical thickness (AOT) measurements with the MICROTOPS II sun photometer when using the manufacturer-supplied default measurement protocol, because this protocol is not sufficient to remove erroneous data points caused by improper pointing at the sun. Porter et al. discussed making changes with respect to sun-pointing problems. While the instrument is deployed at sea, only the highest voltage from a sequence of 25 measurements, rather than the average of the top 4 voltages of a sequence of 32 measurements, is to be saved in the instrument's memory. Once on land, an iterative process, based upon the variability of each set of measurements, is used to reject measurements contaminated by sun-pointing errors. We compared measurements made with these changes to the manufacturer-supplied default measurement protocol while at sea, and refined the iterative rejection routine to reflect the uncertainty analysis of Pietras et al. (2002) and the statistical analysis of maritime aerosols by Smirnov et al. (2002). We also demonstrate a method to remove erroneous measurements from data previously collected by the manufacturer-supplied default MICROTOPS II measurement protocol.

Figure 1 shows the MICROTOPS II sun photometer in use. The operator points the instrument at the sun, and presses the ''Enter'' button. The voltage is stored for each of the five detector bands (typically centered at 440, 500, 675, 870, and 936 nm), along with the

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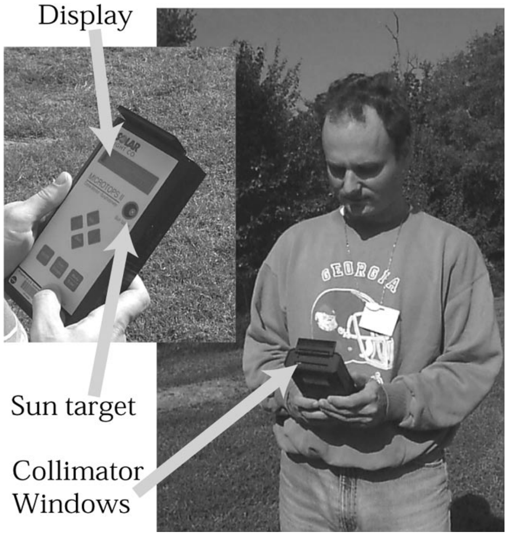

FIG. 1. MICROTOPS II sun photometer in use.

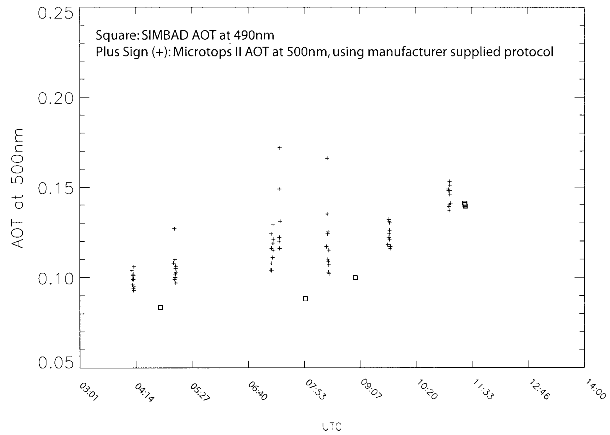

FIG. 2. AOT values measured by two sun photometers during the Indian Ocean Experiment (INDOEX) cruise off southern India on 10 Mar 1999. Note the large range of values associated with each set of MICROTOPS II measurements. This range is due, in part, to sun-pointing errors.

ambient pressure, and latitude and longitude coordinates. Aerosol optical thickness [AOT, or $\tau(\lambda)$] values are calculated for each band (except the 936-nm band, which is used to determine water vapor content) from instrument voltages using the following relationship (Frouin et al. 2001; Volz 1959):

$$V(\lambda) = V_o(\lambda)\left(\frac{d_o}{d}\right)^2 e^{-M\tau(\lambda)} t_g(\lambda), \tag{1}$$

where λ is the center wavelength of the detector band; $V(\lambda)$ is the measured detector voltage in the band with a center wavelength of λ; $V_o(\lambda)$ is the voltage expected at the top of the atmosphere, and expresses the calibration for the band with a center wavelength of λ; d_o/d accounts for the earth–sun distance as it varies with the day of the year; M is the air mass, based on the solar zenith angle; $\tau(\lambda)$ is the total optical thickness; and $t_g(\lambda)$ is the transmission of absorbing gases.

Figure 2 shows AOT values from two instruments. The range of the MICROTOPS II values is well beyond the uncertainty of the instrument (0.015; Pietras et al. 2002). Note the bias associated with MICROTOPS measurements with respect to data from the Simbad radiometer (designed by Laboratoire d'Optique Atmosphérique). (Fougnie et al. 1999; Deschamps et al. 2002, manuscript submitted to *Appl. Opt.*, hereafter DFFLV). The lowest AOTs for each set of MICROTOPS II points represent actual physical values, as erroneous measurements collected with poor pointing will produce unrealistically high AOTs. Like the MICROTOPS II, the Simbad is pointed directly at the sun; however, it avoids pointing problems by using a higher measurement rate (10 Hz) and by keeping only the lowest AOT value of a set of 10. (Fougnie et al. 1999; DFFLV).

2. Method

The MICROTOPS II instrument has a manufacturer-supplied default screening protocol intended to solve the pointing-error problem. Figure 2, in addition to Porter et al. (2001), illustrates that the default protocol is not sufficient for unstable platforms, such as a ship at sea. If the MICROTOPS II is to be used as part of the Sensor Intercomparison and Merger for Biological and Interdisciplinary Oceanic Studies (SIMBIOS) Project, a method to correct for pointing errors at sea must be found.

The manufacturer-supplied default MICROTOPS II protocol is to make 32 samples (over a period of about 10 s) for each measurement, and to save the average of the 4 top voltages to the data file. These four top voltages represent the four lowest AOT values, and thus the four samples least likely to be pointed incorrectly at the sun (Morys et al. 2001). While this protocol may be adequate for measurements taken on land, it is inadequate for use at sea. Ship motion increases the possibility that one or more of the top voltages represents a measurement that was made while it was not pointed accurately at the sun. The result is to bias the data to higher AOT values. This is especially apparent in Fig. 2, in which a set of measurements made over a period too short for AOT conditions to change shows a variance much greater than the calculated uncertainty of the instrument (0.015) [Pietras et al. (2001, 2002), based upon method presented in Miller et al. (2001) and Holben et al. (1998)]. The manufacturer, Solar Light, Inc., suggests mounting the instrument on a tripod for improved accuracy (Morys et al. 2001), but this solution would not help on the moving deck of a ship.

To reduce the possibility of recording data with pointing-error contamination, the measurement protocol was changed based on the suggestions of Porter et al. (2001). Unlike the manufacturer-supplied protocol, which saves the average of the 4 largest (out of 32) voltage values, the proposed protocol logs the largest single value of 20 measurements. This has several advantages. The largest voltage is the only value recorded, so the chance of keeping a contaminated point is minimized. In addition, the total time needed to make this measurement is smaller than with the default protocol, so more measurements can be taken in a short period of time. Furthermore, erroneous measurements are not averaged with valid measurements, so they are much easier to distinguish and remove. After the experiment, a postprocessing algorithm is applied. This algorithm calculates a coefficient of variation (CoV) value for each set of measurements in each band. The CoV is a normalized metric used to analyze the variance within a set of measurements, calculated as

$$\mathrm{CoV} = \frac{s}{\overline{X}}, \tag{2}$$

where s is the sample standard deviation and $\overline{X}$ is the sample mean.

If the CoV is above a threshold of 0.05, the highest AOT value is removed, and the CoV is recalculated. This calculation is repeated until the CoV is less than 0.05 or there are not enough points left to calculate the standard deviation. The ‘‘passed’’ points are those that passed this iterative process in all bands. The CoV threshold of 0.05 was chosen as a conservative estimate of what the CoV would be if the standard deviation was half the instrument uncertainty (0.015; Pietras et al. 2002) and the mean AOT was 0.07, which is an estimate of average maritime AOT at visible wavelengths by Smirnov et al. (2002).

While the CoV-based protocol and processing algorithm will reduce pointing errors in new data, several years of data have already been archived with the manufacturer-supplied protocol. The Sea-Viewing Wide Field-of-View Sensor (SeaWiFS) Bio-Optical Archive and Storage System (SeaBASS; http://seabass.gsfc.nasa.gov) contains MICROTOPS II AOT data from 1997 to the present. To remove data with pointing errors, raw voltage files were reprocessed and sent through a screening algorithm. This algorithm removes measurements that have a standard deviation (of the four averaged points) that exceeds the instrument AOT uncertainty of 0.015. This method is less successful than changing the protocol entirely but is an appropriate fix for archived data.

Figure 3 shows a diagram of the manufacturer-supplied protocol logic, next to a diagram of the proposed CoV-based measurement protocol logic. The starting logic of the two protocol types are similar, but the CoV-based protocol includes a more rigorous postprocessing algorithm performed after the experiment.

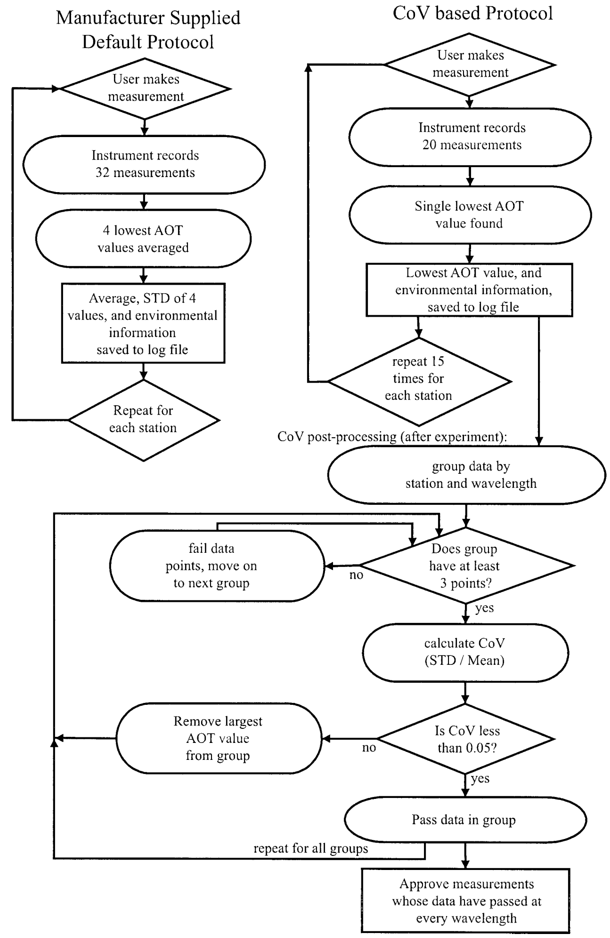

FIG. 3. Logic schematics for the (left) manufacturer-supplied protocol and (right) CoV-based protocol. The manufacturer protocol is performed at the time of measurement and is similar to the first part of the CoV protocol. The CoV protocol, however, contains an iterative postprocessing routine performed after the experiment, which removes data contaminated by pointing errors.

3. Results

Two simple screening techniques, intended to remove sun-pointing errors from MICROTOPS II data collected on unstable platforms, are presented in this paper. The first, and recommended, technique uses a change in the manufacturer-supplied instrument measurement protocol and a postprocessing algorithm. A second technique, based on an examination of the standard deviation of averaged samples, is an adequate method to salvage historical data.

Figure 4 shows a comparison of MICROTOPS II data collected simultaneously with both the manufacturer-supplied and CoV-based protocols. The CoV protocol produces data that have considerably less scatter.

Figure 5a shows results from a recent California Cooperative Oceanic Fisheries Investigations (CalCOFI) cruise off the coast of California, where MICROTOPS II measurements were made under moderately rough sea conditions using the CoV protocol. Once on shore, the data were screened according to the method described above. Generally, the lowest AOT values in each dataset are passed. However, this is not uniformly true, as points

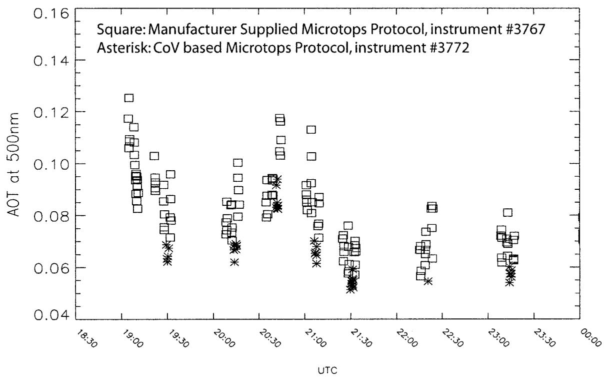

FIG. 4. Comparison of data collected on the CalCOFI cruise off California on 22 Jul 2001 with both the manufacturer-supplied and the CoV-based MICROTOPS II protocol.

are passed based on results in all bands. Since the readout electronics on the MICROTOPS II do not log instrument voltages simultaneously, it is possible to record data that represent pointing errors at only a few wavelengths. Figure 5b shows similar results, from a recent cruise in Massachusetts Bay. To date, these are the only MICROTOPS II datasets archived in SeaBASS taken

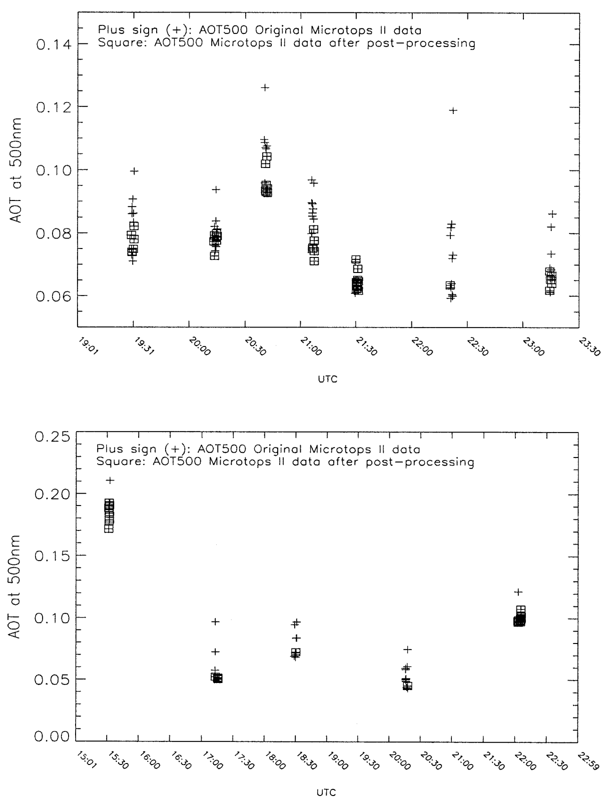

FIG. 5. Data collected with the CoV-based MICROTOPS II measurement protocol and screened with the new postprocessing algorithm. Note that the range of passed points does not usually exceed the AOT uncertainty of 0.015. (a) Data collected on the CalCOFI cruise off California on 22 Jul 2001; (b) data collected in Massachusetts Bay on 26 Feb 2002.

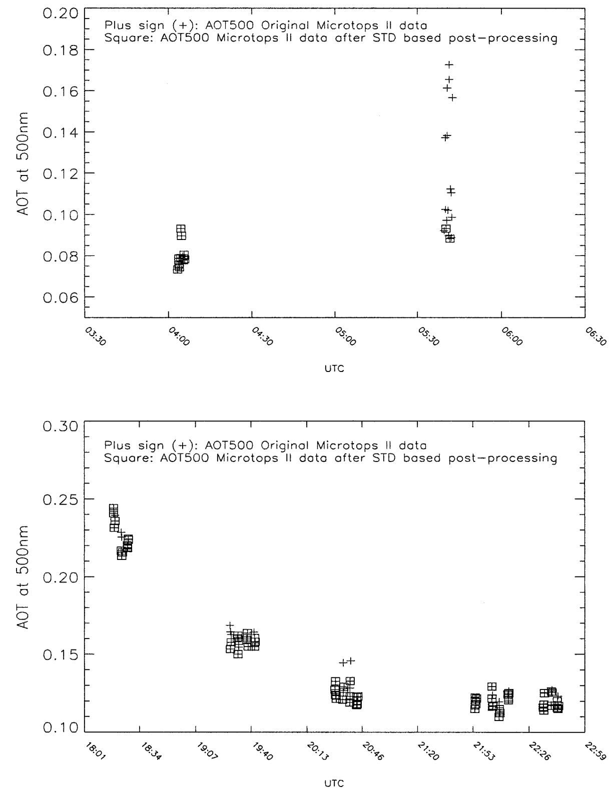

FIG. 6. Data collected with the manufacturer-supplied MICROTOPS II measurement protocol and screened with the standard deviation–based algorithm. Note that the range of passed points, as in Fig. 5, does not usually exceed the AOT uncertainty of 0.015. (a) Data collected on the Trichodesmium Toto (TRICHOTOTO) cruise on 9 Nov 1999; (b) data collected on the CalCOFI cruise off California on 17 Jul 2001.

with the CoV protocol, but they are sufficient to validate the CoV protocol and postprocessing methods.

Figure 6 shows results of the standard deviation–based screening intended for data measured with the manufacturer-supplied protocol. While the raw data contained a variety of value ranges, screened results all had ranges about the same as instrument uncertainty. The success of this method has allowed us to reprocess archived MICROTOPS data and salvage the information it contains.

4. Conclusions

The SIMBIOS Project has been collecting aerosol data from the MICROTOPS II for several years. As comparisons with other instruments became available, it became apparent that this particular instrument was collecting data with variability, in a short time span, much higher than the calculated instrument uncertainty. Also, Porter et al. (2001) wrote that high variability is often due to problems pointing the instrument accurately at the sun while on a moving platform such as a boat at sea. Porter et al. recommended reducing the number of measurements averaged into each data point and iteratively removing outliers from the results. We did this, then collected data to test both measurement protocols. Although a sizeable dataset with this new protocol has yet to be captured, comparisons between both protocol types and with data from other instruments show that this is a viable method to reduce or remove the sun-pointing-error problem. This protocol and postprocessing algorithm has been incorporated into the operational SIMBIOS deployment strategy for all future MICROTOPS II use.

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